BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B69 04092

SUBJECT: Status Report - LM RCS Plume Impingement on the AM/MDA Radiator - Case 620

DATE: April 23, 1969

FROM: J. E. Waldo

ABSTRACT

[redacted]

Degradation of the thermal performance of the AM/MDA radiator can result from RCS plume impingement during LM-A docking. The extent of this degradation is unknown and cannot be analyzed with confidence.

The McDonnell Douglas Corporation has proposed that close-in LM-A thrusting towards the radiator be avoided except in emergencies. Man-in-the-loop simulations by MDC show that docking velocities can be held within the 0.1 to 1.0 fps limits without close-in braking.

Test and flight information indicate the current AM radiator coating, Z-93, is more susceptible to contamination than another, similar, zinc oxide-type, S-13G. Test data on the effects of plume impingement are limited, and the reported data currently available to the author on the thermal coatings of interest are not consistent.

AM thermal performance requirements are greatest during EVA/IVA, when 45°F water must be provided for the Liquid Cooled Garment. It appears that these requirements could be reduced for AAP 3-4, when the AM radiator performance might be degraded. During Mission 3-4 the LM-A also provides for EVA for the ATM, and the only IVA-type support the AM provides is for Experiment M-171. M-171 requires IVA umbilical operation for less than an hour, one man suited at a time.

An Ad Hoc Working Group on contamination has been formed under the ECS/Thermal Subpanel. This group is to set up a joint test program on contamination of thermal control surfaces, with current emphasis on RCS.

(NASA-CR-106872) LM RCS PLUME IMPINGEMENT ON THE AM/MDA RADIATOR STATUS REPORT (Bellcomm, Inc.) 16 p

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MEMORANDUM FOR FILE

INTRODUCTION

If the LM RCS +X thrusters are used during LM/ATM docking to Port 1 of the MDA, their plumes will impinge directly on the AM/MDA radiator. This could introduce a surface heating and contamination problem, surface thermal property degradation, and a potential thermal problem for the AM/MDA radiator. The extent of surface degradation depends on thruster-to-surface distances and angles, the thrust profile, duration of pulse, radiator surface coating characteristics, surface temperature, and the propellants used.

The attached figure shows the LM-A in docking position at Port 1. The three views show the relative distances and thrusting directions of the LM-A RCS thrusters relative to the AM/MDA and the radiators, shown shaded. The lowest view, looking into Port 1, shows that the +X thrusters are directed approximately tangent to the AM/MDA.

The purpose of this memorandum is to discuss proposed solutions for the AM/MDA radiator degradation and to report the status of pertinent analyses and tests.

SURFACE HEATING AND CONTAMINATION

In general, RCS plume impingement is undesirable because of heating and contamination of the impinged surface and the resulting degradation of the surface coating. The effects of heating have been measured. The actual mechanisms of contamination are not well understood and, at present, the extent of contamination for a given set of conditions cannot be analyzed. It appears there are combined effects of direct deposition and later chemical reaction with the surface involving reaction products and incomplete or intermediate reaction products in the exhaust. In addition to the direct effect of surface contaminants, there is interaction between the contaminant film and the space radiation environment. Short, pulsed mode thrusting produces both the most contaminants and the greatest uncertainty in the location of surfaces that will be affected. Contamination has been experienced in and behind the exit plane of the thruster. Observers report unburned propellants from startup or shutdown leave the thruster at the beginning of firing and ignite when away from the thruster. Also, unburned propellant creeps out on the thruster nozzle and is forced off the nozzle lip at undetermined angles.[1]

McDONNELL DOUGLAS ANALYSIS AND PROPOSED SOLUTION

Performance degradation from plume heating and contamination for a given LM-A docking profile cannot be analyzed with confidence. However, McDonnell Douglas Corporation (MDC) has estimated for the purpose of analysis that the solar absorptivity of the present radiator coating, Z-93, may be increased from an undegraded value of about 0.19 to 0.4, based on Grumman test data[2] and a North American report issued by the Air Force (AFR PL-TR-67-3, February 1967). MDC reports that analyses for 0.4 on the LM-A side of the radiator and 0.25 on the opposite side away from the sun show that AM thermal control performance is adequate for normal loads, but inadequate to provide 45°F water to the Liquid Cooled Garment during EVA/IVA.[3] (Martin analyses for MSFC R-P&VE indicate performance is marginal if solar absorptivity increases to 0.3.)[4]

MDC proposed to the Second AAP Guidance and Control Requirements Meeting that the contamination problem be avoided or minimized by modifying the LM-A thruster firing toward the MDA: "1) Make retrograde maneuvers an emergency-only operation during the final phase of docking, and 2) Modify the jet logic during close-in docking, so that pitch and yaw control commands do not fire the forward pointing jets or at least do not fire jets 1 and 5." (See page 3 of the attached MDC briefing charts, Reference 5). If this can be done, the most severe, direct plume impingement is avoided. Man-in-the-loop simulations by MDC indicate docking velocities can be held within the +X docking limits of 0.1 and 1 fps without close-in braking. The MDC proposed approach will be presented at the next meeting of the ECS/Thermal Subpanel.

AM RADIATOR COATING

The white paint planned for the AM radiator is designated as Z-93. This is a potassium silicate pigmented with zinc oxide. It was used on Gemini and is used on the Apollo SM radiators. Test data and experience indicate Z-93 is more susceptible to contamination than S-13G, a similar but newer coating planned for the LM-A radiator and the back-side of the ATM and OWS solar arrays.[6] Z-93 is more susceptible to contamination from ground handling and cannot be cleaned; it must be repainted, and is difficult to apply. Some procedures developed during Apollo have reduced these problems.

S-13G designates a white paint made of zinc oxide encapsulated in potassium silicate with a methyl silicone binder. S-13G was developed to replace the widely used S-13 when it was found that S-13 degraded significantly under the vacuum and ultraviolet conditions of space. IIT Research Institute reports the following values for an 8 mil undegraded S-13G coating: $\alpha_s = 0.19 \pm 0.02$, and $\varepsilon = 0.88 \pm 0.05$. IITRI indicates an increase in α_s of 0.03 after exposure to 1000 equivalent sun hours. The ultraviolet degradation data were obtained experimentally using in situ reflectance measurements in a vacuum chamber. Flight data from Lunar Orbiter I and IV and Mariner V indicate greater degradation, with increases of 0.15 after exposure to 1000 equivalent sun hours.

The effect of plume impingement on S-13G (and other coatings) has received less attention than the effects of ultraviolet and vacuum. The only tests known to the author that specifically cover S-13G degradation due to RCS plume impingement were sponsored by GAEC and were conducted by Astrosystems. These tests used a microthruster and N_2O_4/N_2H_4-UDMH to expose several thermal coating samples, including Z-93 and S-13G.(2) Although in situ measurements were planned, the reported data are from measurements made at the Grumman Thermal Laboratory after the exposed specimens had been removed from the chamber. Problems in the tests make interpretation of the reported data difficult. Some of the major conclusions reported are:

"1) The mechanism causing degradation/contamination of the thermal control surfaces was deposition of exhaust products and/or chemical reaction of exhaust products with the surfaces.

2) Thermal control coatings which exhibit porous surfaces are more vulnerable to contamination effects (i.e. Z-93 vs. Schjeldahl).

3) The degree of degradation varies inversely with distance from the nozzle exit plane and inversely with angular distance from the nozzle center line."

OTHER APPROACHES

Radiator covers for the AM are not being seriously considered because of mechanical complexity. Plume deflectors for the LM-A are not being considered because of questionable effectiveness and reduced efficiency. Other suggestions for reducing contamination by removing contaminants from the exhaust are under study outside AAP.

TESTS

Planned tests that would provide some data are:

1) MSC plans an Apollo LM RCS thruster impingement test on Apollo LM insulation and deflectors. The duty cycle will be for a descent profile involving maximum total duration downward thrusting, including several firings of 1 second, 6 seconds, and pulsed mode. The engine will be rotated to impinge on different specimens for each of the firings. McDonnell has arranged to provide Z-93 and S-13G coating specimens mounted at three different angles for exposure during one of the 6 second firings. This will be a steady firing aimed towards plume heating of the CM ablator, rather than pulsed firing that would generate contamination products. This test is scheduled for late April and, reportedly, cannot be changed because of the test chamber schedule.

2) Lewis Research Center is about to begin a long-term test program using a microthruster and N_2O_4/MMH. Samples will be measured in situ.

3) Arnold Engineering Development Center has been testing coatings for MOL using a microthruster and N_2O_4/MMH. These tests are conducted in a chamber that does not have sufficient vacuum to allow full plume development. Also, sample measurements are made outside the chamber.

Current Apollo flight data should be useful. Samples from Apollo 9 are being analyzed at MSC Structures and Mechanics Division and the results should be available soon. Preliminary results indicate post flight solar absorptivity values do not exceed 0.25, which is the lower limit of degradation assumed by MDC in their analyses. It is interesting to note that Apollo 9 photographs show that boost heating and RCS firings at the time of transposition and dock had caused only slight paint blistering and no cork charring.

MSC plans to analyze the MDC simulation data and combine this information with the results of the current RCS plume impingement test and past studies by P&PD. MDC simulation data are being requested in the form of profile RCS duty cycle vs. LM-A distance for different initial conditions. It is expected this will be discussed by the Mission Requirements Panel.

COMMENTS

It is clear, from the information available at present, that the effects of RCS plume impingement on thermal coatings are not sufficiently well understood to allow confident prediction of the performance of the AM thermal control system. This performance is important. As currently planned, it provides thermal control for the AM, MDA, OWS, and EVA/IVA; and humidity control for the entire cluster.

AM thermal performance requirements are greatest during EVA/IVA, when 45°F water must be provided for the Liquid Cooled Garment. It appears that these requirements could be reduced for AAP 3-4, when the AM radiator performance might be degraded. During Mission 3-4 the LM-A also provides for EVA for the ATM, and the only IVA-type support the AM provides is for Experiment M-171. M-171 requires IVA umbilical operation for less than an hour, one man suited at a time.

Test data summarized in Reference 1 represent a reasonably complete review of the available information on rocket plume contamination. However, more detailed information is required on the specific coatings of interest, Z-93 and S-13G, than is found in this reference. At the time this memorandum was written several additional sources had been identified but had not been received for review.

The ECS/Thermal Subpanel on February 4, 1969 formed an Ad Hoc Working Group on contamination. This group is to set up a joint test program to include all sources of contamination of thermal control surfaces, with current emphasis on RCS. This group is chaired by J. Moses/MSFC and includes representatives from MSC and the contractors.

J. E. Waldo

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Attachments
References
Figures

REFERENCES

1. Borson, E. N. and Landsbaum, E. M. "A Review of Available Rocket Plume Contamination Results", The Aerospace Corporation, Unclassified Report, undated.

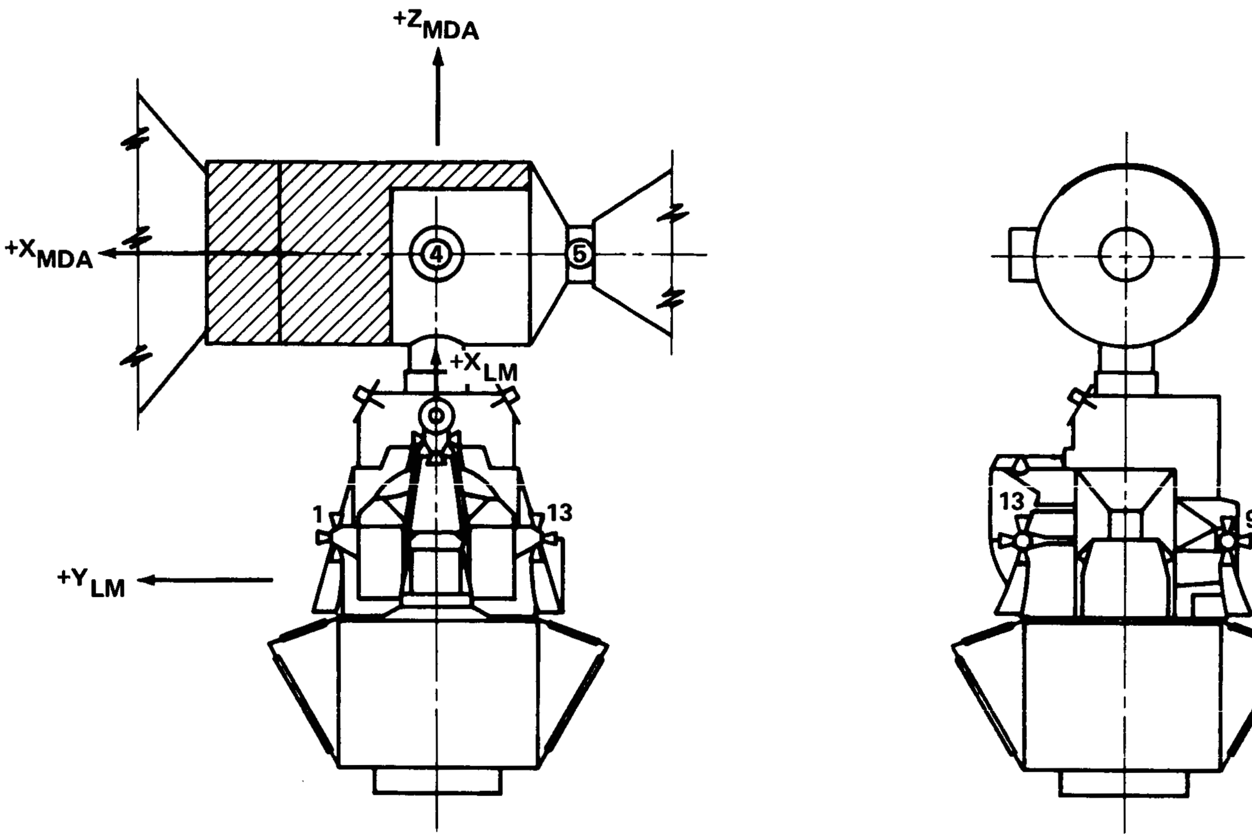
2. Grumman Report LTR-510-2, "Results of Test Program Performed to Evaluate the Effects of Spacecraft Reaction Control Engine Exhaust Impingement on Thermal Control Surfaces", March 1, 1967.

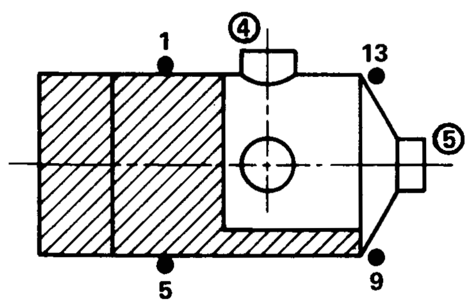
3. Personal Communication, L. D. Calhoun, McDonnell Douglas Corporation, April 14, 1969.

4. Personal Communication, G. D. Hopson, MSFC R-P&VE-PT, April 14, 1969.

5. "Potential Problem - AM Radiator Degradation Due to LM Jet Impingement", McDonnell Douglas Corporation, Enclosure 18 to the Minutes of the Second AAP Guidance and Control Requirements Meeting, January 21, 1969.

6. Working Papers distributed at Ninth ECS/Thermal Subpanel Meeting, February 4, 1969, by A. R. Mendelsohn, Grumman Aircraft Engineering Corporation; based on Reference 2 data.





①,④,⑤ MDA PORT NUMBERS

1, 5, 9, 13 LM-A +X THRUSTERS

FIGURE - LM-A RCS THRUSTER AND MDA/AM RADIATOR LOCATIONS

ENCLOSURE 18

POTENTIAL PROBLEM
AM RADIATOR DEGRADATION DUE TO LM JET IMPINGEMENT

1. DURING LM/ATM REMOTE DOCKING THE LM BRAKING JETS, ALSO USED FOR PITCH AND YAW, CAN POTENTIALLY DEGRADE THE PERFORMANCE OF THE AM RADIATOR. IF DEGRADATION OCCURS, IVA-EVA OPERATIONS WOULD BE UNCOMFORTABLY WARM FOR THE CREW DURING MISSION 3/4.

2. THE COMBINATION OF AEROSPACE, MARQUART AND ASTROPOWER LABS ARE CURRENTLY INVESTIGATING METHODS OF REMOVING CONTAMINANTS FROM THE EXHAUST, IN ADDITION TO STUDYING THE EXTENT OF THERMAL COATING DEGRADATION WITH A 22# THRUSTER.

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ENCLOSURE 18

CHARACTERISTICS OF RCS PLUME/RADIATOR DEGRADATION

- DEGREE OF DEGRADATION DEPENDENT ON DISTANCE FROM NOZZLE EXIT, DISTANCE FROM NOZZLE CENTERLINE AND ANGLE OF IMPINGEMENT. (REFERENCES: GRUMMAN RPT. LTR-510-2 AND USAF(RPL) TR-67-3)
    - DEGRADATION EFFECTS SMALL FOR SURFACES PARALLEL TO RCS STREAMLINES
    - DEGRADATION EFFECTS LARGE FOR SURFACES NORMAL TO RCS STREAMLINES
        - POTENTIAL FOR UP TO 200% INCREASE IN AM RADIATOR SOLAR ABSORPTIVITY BASED ON AVAILABLE DATA FOR Z-93 RADIATOR COATING
    - EXPERIMENTAL DATA INCOMPLETE BUT INDICATES FULL DEGRADATION IS EXPERIENCED WITHIN THE FIRST SECOND.
    - ANALYSIS NOT POSSIBLE DUE TO LACK OF KNOWLEDGE ABOUT DEGRADATION PROCESSES.
- METHODS NEED TO BE STUDIED WHICH WILL ELIMINATE CONTAMINANTS FROM RCS PLUMES OR PREVENT IMPINGEMENT OF THE LM OR CSM RCS PLUMES ON THE AM RADIATOR

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POTENTIAL CONTROL SYSTEM MODIFICATIONS TO MINIMIZE THIS PROBLEM

1. MAKE RETROGRADE MANEUVERS AN EMERGENCY-ONLY OPERATION DURING THE FINAL PHASE OF DOCKING.

2. MODIFY THE JET LOGIC DURING CLOSE-IN DOCKING, SO THAT PITCH AND YAW CONTROL COMMANDS DO NOT FIRE THE FORWARD POINTING JETS OR AT LEAST DO NOT FIRE JETS 1 AND 5.

ENCLOSURE 1B

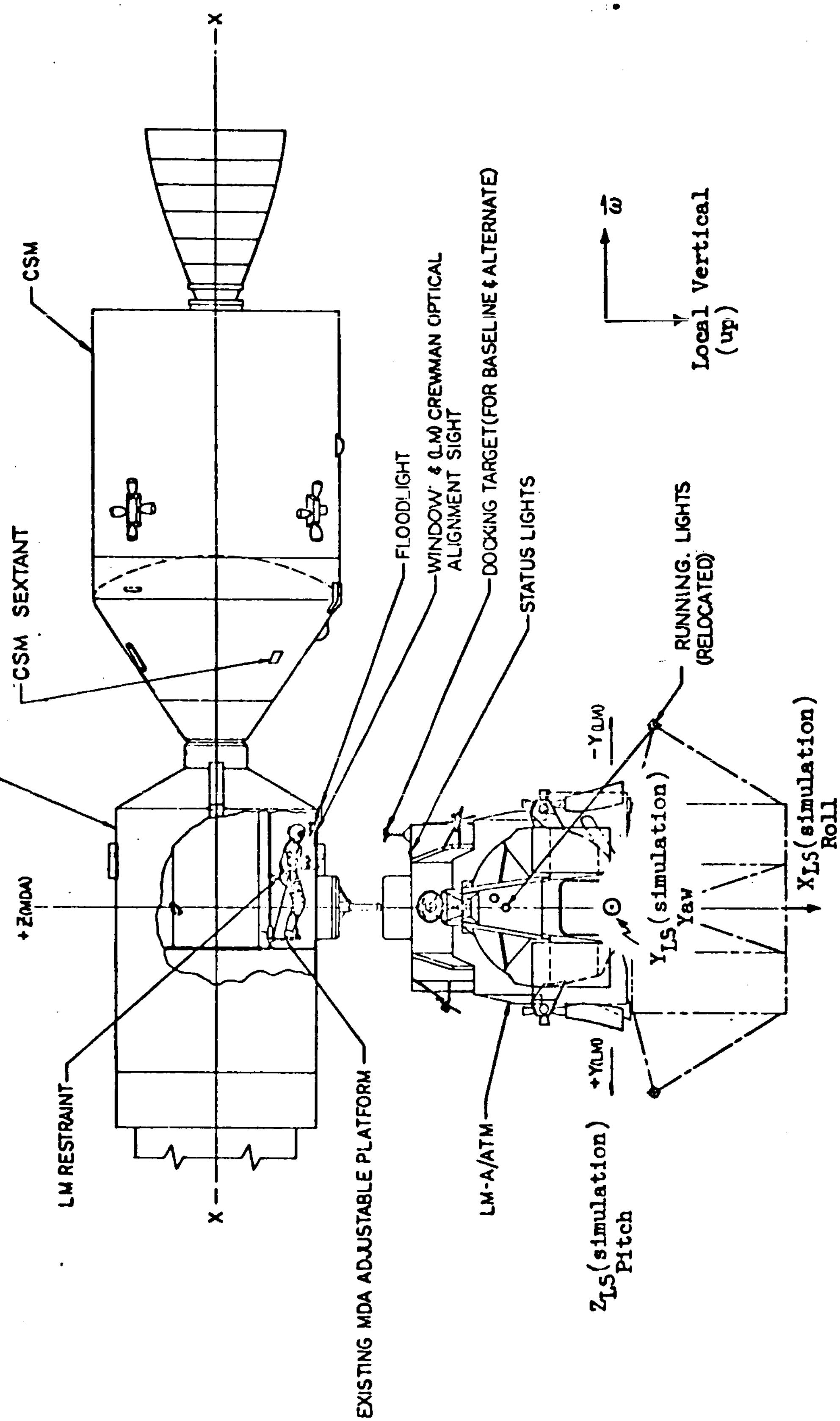


Figure 1

AAP 3/4, LM/ATM DOCKING CONFIGURATION

JET POLICY TABLES

ILLUSTRATING POLICY WITH JETS 1, 5, 9, AND 13 UNUSABLE

+Q-AXIS ROTATION:

1. 2-5-9-14
2. 2-5
3. 9-14
4. 2-14
5. 5-9

-Q-AXIS ROTATION:

1. 1-6-10-13
2. 1-6
3. 10-13
4. 1-13
5. 6-10

+R-AXIS ROTATION:

1. 1-5-10-14
2. 1-14
3. 5-10
4. 1-5
5. 10-14

-R-AXIS ROTATION:

1. 2-6-9-13
2. 6-9
3. 2-13
4. 2-6
5. 9-13

+U-AXIS ROTATION:

1. 5-14
2. 14
3. 5

-U-AXIS ROTATION:

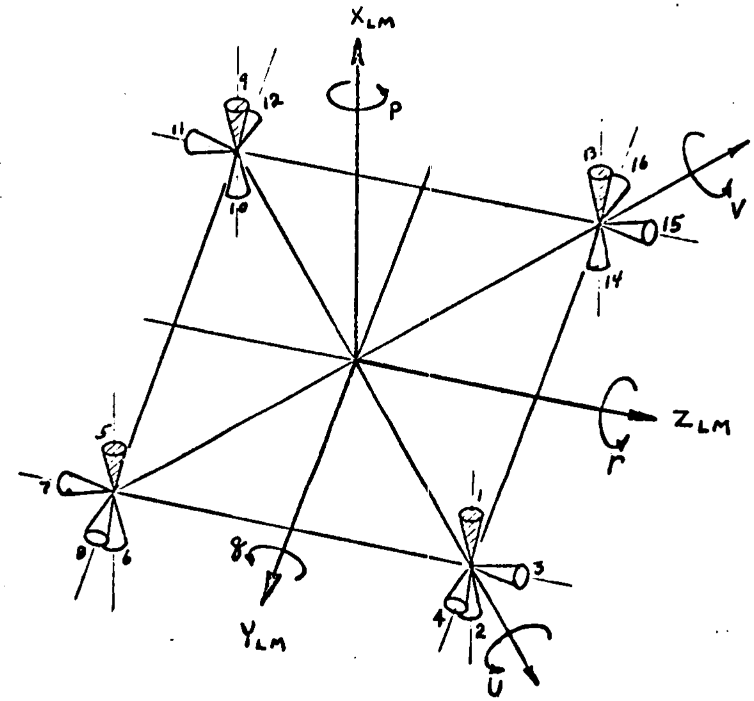
1. 6-13
2. 6
3. 13

+V-AXIS ROTATION:

1. 1-10
2. 10
3. 1

-V-AXIS ROTATION:

1. 2-9
2. 2
3. 9



- THE FIRST TABLE ENTRY IS THE POLICY SELECTED IF ALL 16 JETS ARE AVAILABLE.
- THE SUBSEQUENT ENTRIES ARE THE NEXT MOST DESIRABLE JET SELECTIONS IN CASE OF JET FAILURES.
- THE CIRCLED ENTRIES ARE THE SELECTIONS NECESSARY IF JETS 1, 5, 9 AND 13 ARE NOT AVAILABLE. ALL OF THESE RESULT IN DISTURBANCE TRANSLATIONS.
- THE P-AXIS (NOT SHOWN IN TABLE) IS UNCHANGED BY ABSENCE OF JETS 1, 5, 9, AND 13.

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JET POLICY TABLES
ILLUSTRATING POLICY WITH JETS 1 AND 5 UNUSABLE

+Q-AXIS ROTATION:
1. 2-5-9-14
2. 2-5
3. 9-14
4. 2-14
5. 5-9

-Q-AXIS ROTATION:
1. 1-6-10-13
2. 1-6
3. 10-13
4. 1-13
5. 6-10

+R-AXIS ROTATION:
1. 1-5-10-14
2. 1-14
3. 5-10
4. 1-5
5. 10-14

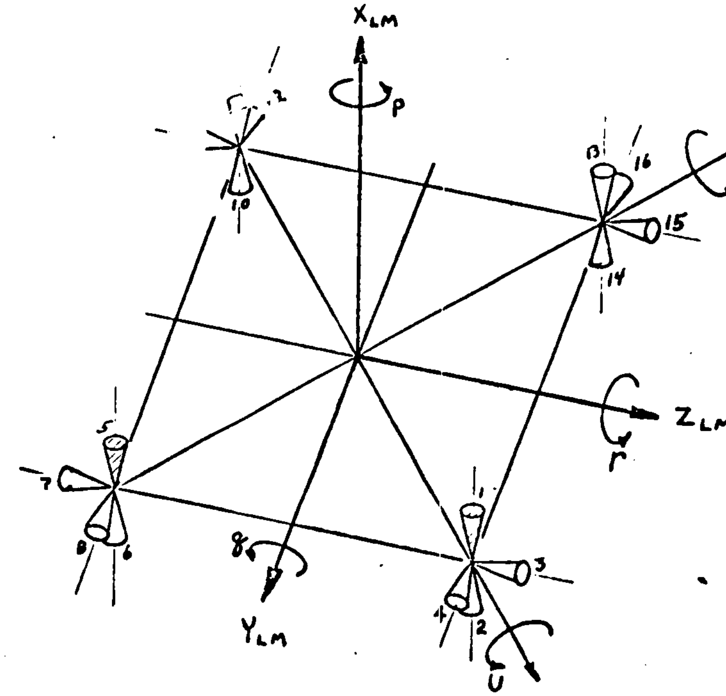
-R-AXIS ROTATION:
1. 2-6-9-13
2. 6-9
3. 2-13
4. 2-6
5. 9-13

+U-AXIS ROTATION:
1. 5-14
2. 14
3. 5

-U-AXIS ROTATION:
1. 6-13
2. 6
3. 13

+V-AXIS ROTATION:
1. 1-10
2. 10
3. 1

-V-AXIS ROTATION:
1. 2-9
2. 2
3. 9



- THE FIRST TABLE ENTRY IS THE POLICY SELECTED IF ALL 16 JETS ARE AVAILABLE.
- THE SUBSEQUENT ENTRIES ARE THE NEXT MOST DESIRABLE JET SELECTIONS IN CASE OF JET FAILURES.
- THE CIRCLED ENTRIES ARE THE SELECTIONS NECESSARY IF JETS 1 AND 5 ARE NOT AVAILABLE. DISTURBANCE TRANSLATIONS RESULT FROM +R, -R, +U, AND +V ROTATIONS.
- THE P-AXIS (NOT SHOWN IN TABLE) IS UNCHANGED BY ABSENCE OF JETS 1 AND 5.

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PROBLEMS ASSOCIATED WITH THIS SOLUTION

1. INSUFFICIENT PITCH AND YAW CONTROL AUTHORITY DURING RADIAL TRANSLATION BURNS

2. PITCH AND YAW FIRINGS WOULD RESULT IN NET POSIGRADE DELTA VELOCITY INCREMENTS DURING THE PERIOD WHEN THIS MODIFIED JET LOGIC WAS INFORCE.

BELLCOMM, INC.

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From: J. E. Waldo

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